NATIONAL BUREAU OF STANDARDS REPORT

7542

PROGRESS REPORT

OF

MATERIALS USED IN WATERPROOFING SYSTEMS ON UNDERGROUND STRUCTURES

by

William W. Walton
Thomas H. Boone
William C. Cullen
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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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Sponsored by

Office of the Chief of Engineers
Department of the Air Force
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MATERIALS USED IN WATERPROOFING SYSTEMS ON UNDERGROUND STRUCTURES

1. INTRODUCTION

The use of underground structures has increased in recent years and the waterproofing of these structures is of paramount importance. Multiple-ply, bituminous, built-up membranes have earned an excellent reputation in this respect. However, other organic materials in various forms (sheet, coatings, etc.) have recently shown promise to perform the same function and eliminate some of the difficulties inherently connected with the application and performance of a hot-applied, built-up membrane.

The many factors relating to application techniques and ultimate performance of the newer systems have been recognized by the agencies of the Defense Department. Heretofore, little unbiased information has been available to assist the personnel charged with design and maintenance responsibilities. Therefore, in response to a request of the Chief of Engineers, U. S. Army; Directorate of Civil Engineering, U. S. Air Force; and the Bureau of Yards and Docks, U. S. Navy, a program was conducted to investigate the performance of waterproofing materials and systems, both in the laboratory and in the field.

This report gives the results of the laboratory work and the findings obtained during the field surveys in Fiscal Year 1962.

2. MATERIALS

The first choice of materials for laboratory study were those used or specified for use in facilities that were visited. Later in the program, additional materials and systems were obtained from various sources.

At two sites which were visited, hot-spray vinyl coatings, 20 to 30 mils thick, were observed. (See Sections 4.1.1 and 4.1.2.) At the first site, the material was designated as "Ren Plastic RC 920", manufactured by the Ren Plastics, Inc., Lansing, Michigan. At the second site, the material used for waterproofing the underground control centers was "Gold Bond GP Vinyl Epoxy Primer" with a 20-mil thick coating of "Vinylelastic" placed over the primer. These materials are manufactured by the Coloron Division, Kish Industries, Inc., Lansing, Michigan.

The materials under investigation have been divided into three categories: built-up, sheet, and coating. They are discussed below. A list of the materials and the manufacturers which have been contacted by this laboratory is given in Table I.

2.1 Built-Up

Built-up systems consisting of alternate layers of felt and hot bitumens have a long history of successful performance for below-grade waterproofing. The systems vary, however, with the type and method of applying the bitumen and the number and types of felts or cloth used. In addition to the bituminous materials, high-solids epoxy, epoxy esters, and coal-tar epoxy are used in some cases with membranes and are therefore included in the built-up systems.

2.2 Sheetings

Both rubber and plastic materials ranging from 8 to 100 mils are included in this category. The most popular plastic sheeting is polyvinyl chloride, although the following materials have been suggested: high-density polyethylene, polyesters, vinylidene chloride-vinyl chloride copolymer, and polystyrene. These latter materials have not been emphasized by the plastics industry for this use because of high cost, properties, or application techniques.

2.3 Coatings

The waterproof coating commonly used in the silo construction thus far observed was a vinyl chloride dispersion applied by a hot-spray technique to an epoxy-primed surface. One-coat, epoxy-vinyl systems, high-solids epoxies, epoxy esters, and chlorinated rubber are also being considered for use.

3. APPLICATION METHODS

In addition to possessing the desired physical properties, a material for use in underground waterproofing systems should be capable of being applied by conventional techniques.

TABLE I - MATERIALS

mple	Type	Manufacturer	Designation Trade Names	Brief Discription
		Built-up Membrane		
5	Asphalt emulsion and glass fabric	Flintknote Co. Industrial Div.	Yellow Jacket & Asphalt Emulsion C-13-E	3 ply system of fabric and emulsion
6	Hot asphalt and asphalt felt	---	---	3 ply system of 15 lbs. asphalt felt and hot asphalt
7	Hot coal tar and coal tar felt	---	---	3 ply system of 15 lbs. coal tar felt and hot coal tar
8	Asphalt emulsion and glass fabric	Lion Oil Co.	Nokorode Seal Kote	3 ply system of fabric over asphalt base primer
15	Coal tar epoxy and glass fabric	Pittsburgh Chemical Co.	Tarset (R) Standard	2 coat system of glass fabric and coal tar solution over primer about 8 to 10 mils
16	Coal tar epoxy and glass fabric	Pittsburgh Chemical Co.	Tarset Epoxy x-403	2 coat system of glass fabric and coal tar without primer about 65 to 90 mils
17	Hot coal tar enamel and glass fabric	Pittsburgh Chemical Co.	Plasticized Enamel	2 ply system of hot coal tar enamel and glass fabric

TABLE I - MATERIALS (CON'T)

Sample	Type	Manufacturer	Designation Trade Names	Brief Discription
		Sheeting Membrane		
2	Polyvinyl chloride	Lexsuco Co.	Lexsuco Vinyl Waterproofing	8 mils thick sheet applied with "Lexsuco Adhesive"
3	Polyvinyl chloride	Visking Co.	KDA-2265 Black-35	8 mils thick sheet applied with "Boxer Cement"
4	Rubber-plastic	Rubber & Plastic Compound Co., Inc.	Nervastral & Seal Puff	8 mils thick sheet applied with "Nerva Plast Cement"
9	Rubber-plastic	Rubber & Plastic Compound Co., Inc.	Nervastral & Seal Puff	10 mils thick sheet applied with "Nerva Plast Cement"
10	Rubber-plastic	Rubber & Plastic Compound Co., Inc.	Nervastral & Seal Puff	15 mils thick sheet applied with "Nerva Plast Cement"
11	Rubber-plastic	Rubber & Plastic Compound Co., Inc.	Nervastral & Seal Puff	20 mils thick sheet applied with "Nerva Plast Cement"
12	Rubber-plastic	Rubber & Plastic Compound Co., Inc.	Nervastral & Seal Puff	30 mils thick sheet applied with "Nerva Plast Cement"
18	Rubber-plastic	Amercoat Corporation	Amercoat (T-Lock)	100 mils thick with ribbing that are mechanically embedded in concrete
		Coated Membrane		
1	Hot spray on vinyl	Coloron Div. of Kish Industries	Vinylastic	20 mils thick hot spray polyvinyl chloride applied over epoxy primer
14	Rubber base compound	Tufcrete Co.	Elastomeric Coating	2 coat system about 3/8" thick

3.1 Mopping

Coal-tar enamels, asphalt and coal-tar pitch built-up membranes are always applied hot, and this type of application presents some hazard when working in confined areas. The heating equipment must be located fairly close to the area of application, because too low a temperature at the time of application results in poor bond and inadequate penetration of the felt or cloth.

3.2 Adhering

The flexible plastic sheet systems are bonded and, in some cases, sealed at overlapping ends by thermoplastic adhesives. A thermoplastic adhesive is specified because such an adhesive can closely approximate the properties of the sheet and is likely to better withstand the stresses developed during the expansion and contraction that might occur. These adhesives dry by solvent evaporation, leaving the solid adhesive in place. The nature of the adhesive required is determined by the temperature and other physical requirements of the application and the nature of the materials to be bonded. Besides involving fire and toxicity hazards, the use of adhesives in the field requires careful surface preparation and application.

3.3 Spraying

The vinyls, plastisols, and epoxies in suitable solvent systems may be sprayed with conventional spraying equipment. Equipment is available to mix two component systems in the right proportions at the nozzle, to preheat the material, and to heat the material at the nozzle in order to facilitate faster cure or set. Skilled personnel, with a good understanding of the equipment and material, are required.

3.4 Mechanical

A 100 mil thick polyvinyl chloride with T-extensions of ribbing, spaced at 2 1/2-inch intervals relies on a mechanical bond. This plastic lining material is placed on the concrete side of the forms before pouring the concrete, with the smooth side toward the forms. The concrete flows around the ribs, thus making the plastic an integral part of the finished structure.

4. PROPERTIES

4.1 Field Inspections

Through the cooperation of the Corps of Engineers Ballistic Missile Construction Office and the Bureau of Yards and Docks, the following field inspections were made in Fiscal Year 1962:

Titan I site at Larson Air Force Base
Minuteman sites at Malmstrom Air Force Base
Titan II sites at Little Rock Air Force Base
Miscellaneous Structures

At each location, the Area Engineer was contacted and discussions were held with staff and field engineers on methods and materials used for waterproofing the structures.

4.1.1 Larson Air Force Base

A visit was made to Titan I missile launching complex 1-C to observe systems of waterproofing on underground silos, tunnels, and adjoining structures. With the exception of a few structures near the surface, all work had been covered over.

The silo structures were waterproofed with a two-coat system. A hot-spray primer was applied at a rate of approximately 200 sq. ft. per gallon of a material identified as RC 900, after which a second coat of a material known as RC 920 was applied by a hot-spray technique to a thickness of about 30 mils. The coating system was reported to be a plastic membrane waterproofing of epoxy-polyvinyl chloride as manufactured by Ren Plastics, Inc., Lansing, Michigan.

The corrugated steel utility tunnels were coated with factory-applied asphalt-asbestos mastic.

The adjoining structures were waterproofed with a five-ply asphalt-felt system and protected with 1/2-inch fiberboard.

The site was surrounded by irrigated fields supplied by canals from the Columbia Basin Project and the complex was designed for a water table within a few feet of the surface.

At the time of the visit, the leakage of water into the structures and tunnels at this site was a serious problem. Water was being pumped from the site at a rate of 240,000 to 255,000 gallons per day during the period of 29 July to 9 August. There were numerous leaks around bolts in the tunnels. Leaks were also noted at tunnel junctions. Minor leaks were encountered in the concrete structures, generally at points where bolting into walls had taken place, or where steel members had been welded to ring beams set in the concrete structures.

4.1.2 Malstrom Air Force Base

A visit was made to six Minuteman launch silos and four control centers. The areas visited included all phases of construction.

The control center structures were being waterproofed with a two-coat system. First a hot-spray primer of a material known as "Gold Bond GP Vinyl-Epoxy Primer" was applied to a dry film thickness of 1 mil, and second a hot-spray finish coat called "Vinylelastic" was applied at a dry film thickness of 20 mils. The complete system was reported to be "Lifecoat Vinylelastic Waterproofing Membrane", as manufactured by Coloron Division of Kish Industries, Lansing, Michigan. The primer coat was, in some cases, used as or in place of the concrete curing compound. No protective board was used for back fill. Blisters were observed on some surfaces, but they were reported to disappear in time. Some small areas (1/4 to 1/2 inch) were torn on the membrane at one control center being back-filled.

4.1.3 Little Rock Air Force Base

Three Titan II Missile Sites (2, 15, and 4) were visited at Little Rock Air Force Base, Little Rock, Arkansas. The three sites were at various stages of construction, with site 4 most nearly completed.

The following observations were made during the visit:

Access Port. The access port was a reinforced concrete structure extending about 35 feet underground. The waterproofing system consisted of priming the relatively smooth concrete surface with an asphalt cut-back primer and applying a 5-ply asphalt built-up membrane horizontally. A fiberboard insulating material was used to protect the membrane from damage during the backfill operation.

The condition of the membrane waterproofing varied from site to site. On site 2, the application was excellent, while on site 4, it was poor. The poor condition was evidenced by a lack of adhesion between the plies of felt and severe slippage of the membrane at one area, and could be attributed to application difficulties.

Some difficulty was also experienced with the exposed fiberboard protection of the membrane. In many cases it was observed that the material had curled with a subsequent loss of adhesion to the membrane and hence gave little protection to it. It was suggested that this condition could be eliminated by coating the fiberboard with either hot asphalt or a cold asphalt coating to prevent moisture absorption and the resultant curling.

A point of weakness in the waterproofing system was observed at the junction of the access port and the electromagnetic shield on the blast lock. The original specification did not call for flashing at this point and leakage developed. Currently, a 12-inch strip of asphalt-saturated felt embedded in and coated with a fibrated asphalt emulsion is being successfully employed as a flashing. It was felt that this is a temporary measure and it was suggested that a more permanent type of flashing be designed.

Silos. The construction and waterproofing of silos were also observed at Sites Nos. 2, 4, and 15. The silos were constructed of heavily reinforced concrete and extend about 145 feet below the surface. No waterproofing, per se, was applied to the silo construction. However, a 1/4-inch welded steel plate which serves as an electromagnetic shield and completely encloses the silo, blast lock and control center also acts as the waterproofing member.

It was reported that water leakage had occurred both in the silos themselves and outside the silos in the vicinity of the intake and exhaust ports. There was no question that failures in the form of breaks in the EM shield had occurred. Since it was impossible to attact the problem from the outside of the silo, grouting from the inside was clearly indicated and successfully accomplished.

Grouting with a chemical solution identified as Halliburton Pressure Grouting was the system used and its use was reported as successful on the silo at site No. 2.

The grouting process at Site No. 5 was observed during the inspections. The system consisted of drilling a 2-inch hole through the 4-foot thick concrete wall and injecting the chemical grout under pressure into the area between the EM shield and the concrete wall. The grout initially has a viscosity of water and thickens with time to seal openings in the concrete.

4.1.4 Small Underground Structures

A visit was made to observe the application of a membrane waterproofing system on a two-story buried concrete structure.

The concrete surface was coated with creosote primer and waterproofed with a four-ply, coal-tar-pitch membrane. The membrane consisted of three layers of felt and one ply of cotton fabric mopped to the primed concrete and to each other with hot pitch. A 1/2-inch fiber board was placed for backfill protection.

4.2 Laboratory Inspections

The properties considered to be of greatest importance for the intended application in underground waterproofing systems are as follows:

Water Resistance

- Water-vapor permeability
- Water absorption
- Water-pressure resistance

Resistance to Soil Conditions

- Acids, bases, and salts
- Fungi and bacteria
- Rodents and insects

Strength

- Tensile strength
- Elongation

Toughness

- Tear resistance
- Puncture resistance
- Tear-impact

The properties and methods of test for water-pressure resistance, strength and toughness are discussed in the following sections. Tables II, III, and IV list results of these tests. Table I may be referred to for the identification of the samples that were tested.

4.2.1 Sample Preparations

All samples tested thus far have been received directly from the manufacturers and applied to concrete panels or prepared in a "free film" form according to directions supplied by the manufacturer. The coating-type materials were applied with a brush to the thickness specified by the manufacturer. All materials were dried or cured for the specified time before testing.

4.2.2 Water Resistance

An apparatus has been designed and constructed to subject membranes in the laboratory to conditions simulating those encountered in the field (see Figure 1). The apparatus permits the waterproofing membrane, backed by concrete, to be exposed to water pressures of varying amounts. This treatment is designed to simulate the water-head existing at various depths underground. The apparatus also permits exposure of the membrane to various sizes and types of gravel under varying pressures independent of the water pressure. Table II lists results of tests on some of the materials under one set of test conditions.

4.2.3 Strength

Tensile Strength. Good tensile strength is of basic importance in any material that may be subjected to stress and strain during handling or service. Measurement of this property of plastic sheets, films, or built-up materials was made by ASTM Method D 882, Method B, in which a constant rate of jaw or grip separation was employed. The test specimen was a strip of uniform width and thickness and 4 inches or more in length. The width of specimen was chosen to allow failure to occur well within the load capacity of the machine. A rate of cross-head motion of 20 inches per minute was used. Thickness and width were measured at several points and the minimum cross-section was recorded. Tensile strength was calculated by dividing the maximum load in pounds by the original minimum cross-sectional area in square inches. The average strengths in two directions are reported from specimens made at right angles to each other. The results are listed in Table III.

TABLE II - WATER PRESSURE - BACKFILL

LOAD TEST

(Water pressure = 60 lbs.; Backfill pressure = 600 lbs. 1/)

Sample No.	Results
Built-up Membrane	
5	Failed 2/
6	Passed
7	Passed
Sheeting Membrane	
2	Failed
3	Failed
4	Failed
9	Failed
10	Failed
11	Passed
12	Passed
18	Passed
Coated Membrane	
1	Failed

1/ Pressure applied to sample over a 4- by 6-1/2-inch area with No. 4 pea gravel.

2/ The word "failed" indicates that the membrane would permit water to leak through to the concrete within four hours under the above test conditions.

TABLE III - STRENGTH

Sample No.	Thickness	Breaking Strength lbs.		Tensile Strength psi		Elongation %	
	Mils.	A dir.	B dir.	A dir.	B dir.	A dir.	B dir.
			Built-up Membranes				
5	75	30	18	670	410	0	0
6	225	42	29	290	250	0	0
7	190	20	19	180	170	0	0
			Sheeting Membranes				
2	9	18	18	3600	3600	300	270
3	8	11	9	2190	1720	240	220
4	20	32	25	2700	2070	300	280
9	10	13	11	2260	1880	270	230
10	16	27	19	2890	1960	290	280
11	21	34	25	2540	2030	300	300
12	30	44	38	2700	2140	350	330
18	125	51	49	4100	3860	340	330
			Coat Membrane				
1	30	25	24	1430	1350	230	230

TABLE IV - TOUGHNESS

Sample No.	Thickness	Tear Resistance		Puncture Resistance	45° Tear Impact
		lbs.			
	mils	A dir	B dir	ft	ft
		Built-up Membranes			
5	80	15	15	3	3
6	200	34	29	3	8
7	215	20	18	2-1/2	8
		Sheeting Membranes			
2	9	3	3	2	<2
3	8	2	2	2-1/2	2
4	21	6	5	7	2
9	10	2	2	3-1/2	2
10	16	5	3	5	2
11	22	6	5	7	2
12	30	7	7	>8	2
18	104	46	41	>8	>8
		Coated Membranes			
1	30	10	9	>8	3

Elongation. A moderate elongation is desirable for ease of handling and fitting materials and for keeping stresses generated during installation or service at relatively low levels. While the specimens were being tested for tensile strength, the elongation was recorded to the moment of rupture. The percent elongation was calculated by dividing the elongation at the moment of rupture by the original length and multiplying by 100. The results of the determinations are reported in Table III. The tests were performed on specimens cut in two directions at right angles to each other.

4.2.4 Toughness

The property of toughness, while closely related to strength, implies certain additional qualities. Tear resistance, puncture resistance, and tear-impact are of particular importance.

Tear Resistance. A good tear resistance is desirable for fitting materials and for resisting damage during service. A constant rate grip separation, as described in ASTM D-1004-61, was used to determine the tear strength by measuring the maximum load required to tear through a specially-shaped die-cut specimen and is expressed as pull in pounds per inch of thickness. The specimen had a 90 degree off-set, rounded on the outer edge and forming a right angle at the center of the inner edge, so that a high stress concentration was produced at the center of the specimen when the load was applied. The tear strength value is therefore an indication of the notch sensitivity of the material as well as a function of its tensile strength, elongation, and shear strength. The results of the tear strength are given in Table IV.

Puncture Resistance. A good resistance to puncture would prevent damage to the membranes such as might result from accidental dropping of tools or in back-fill operations. In this test, 10- by 10-inch specimens were held firmly by a wooden frame with a 6- by 6-inch opening in the center. A 200-gram steel dart with a 1/8-inch diameter ball point was dropped vertically onto the center of the specimen. The distance in height that the material would withstand the drop without causing puncture completely through the specimen is recorded in Table IV.

Tear Impact. Another feature of considerable importance is the resistance of the membranes to impact when placed against a concrete surface. In this test, the materials were placed on concrete panels as in actual field applications. The concrete was set up at 45 degrees from the horizontal with the membrane facing upward. A 220-gram steel dart with a 3/4-inch diameter rod, rounded at the end, was dropped vertically onto the specimen. The distance in height that the material would withstand the drop without breaking or tearing the membrane through to the concrete is recorded in Table IV.

5. SUMMARY

Visits were made to Titan I, Titan II, and Minuteman missile sites to observe the performance of waterproofing materials in actual use and to ascertain the practical problems connected with waterproofing techniques in the field. Some of the difficulties could be traced to design deficiencies such as the use of bolted joints in the cableways of the Titan missile sites or the lack of water stops or flashings where needed. These deficiencies are being corrected in present construction. Other problems could be traced to the field conditions. For example, limited working space necessitated carrying the hot asphalt used in built-up membrane waterproofing a distance so great that it became too cool for best application. Another example is the use of curing compounds on the concrete to conserve the water that would be required for curing. The use of these compounds often prevented proper bonding between the concrete surface and an epoxy primer used with a hot-spray polyvinyl chloride-epoxy resin waterproofing treatment. This problem was solved by substituting the epoxy primer for the curing compound.

The polyvinyl chloride-epoxy resin treatment still presents an unsolved problem of occasional blisters. Working space, ventilation, condition of the concrete surface, back-fill operation, time schedules, and availability of experienced personnel are some of the important field conditions that must be considered in the solution of a waterproofing system.

The laboratory data are insufficient for specific conclusions, but they do indicate general trends. Samples with breaking strengths 32 pounds or lower failed in the simulated water pressure-back-fill load test with the exception of sample No. 7, which had a breaking strength of 20 pounds in one direction and 19 pounds at a right angle direction. Sample No. 11, which also passed the simulated test, had a breaking strength of 34 pounds in one direction and 25 pounds at a right angle direction.

The percent elongation showed no correlation with the simulated test, but this property may have some importance during installation.

Samples with high tear resistance, puncture resistance, and 45° tear impact resistance passed the simulated test, but there are a number of exceptions. Sample No. 4, which failed this test, had the same values for all three properties as sample No. 11 which passed. Also, sample No. 5, which failed the simulated test, had a much higher tear resistance than either samples No. 11 and 12, although it should be noted that its value was lower than samples Nos. 6 and 7 of similar type.

The significance of any of these tests, including the water pressure-back-fill load test, has not been established.

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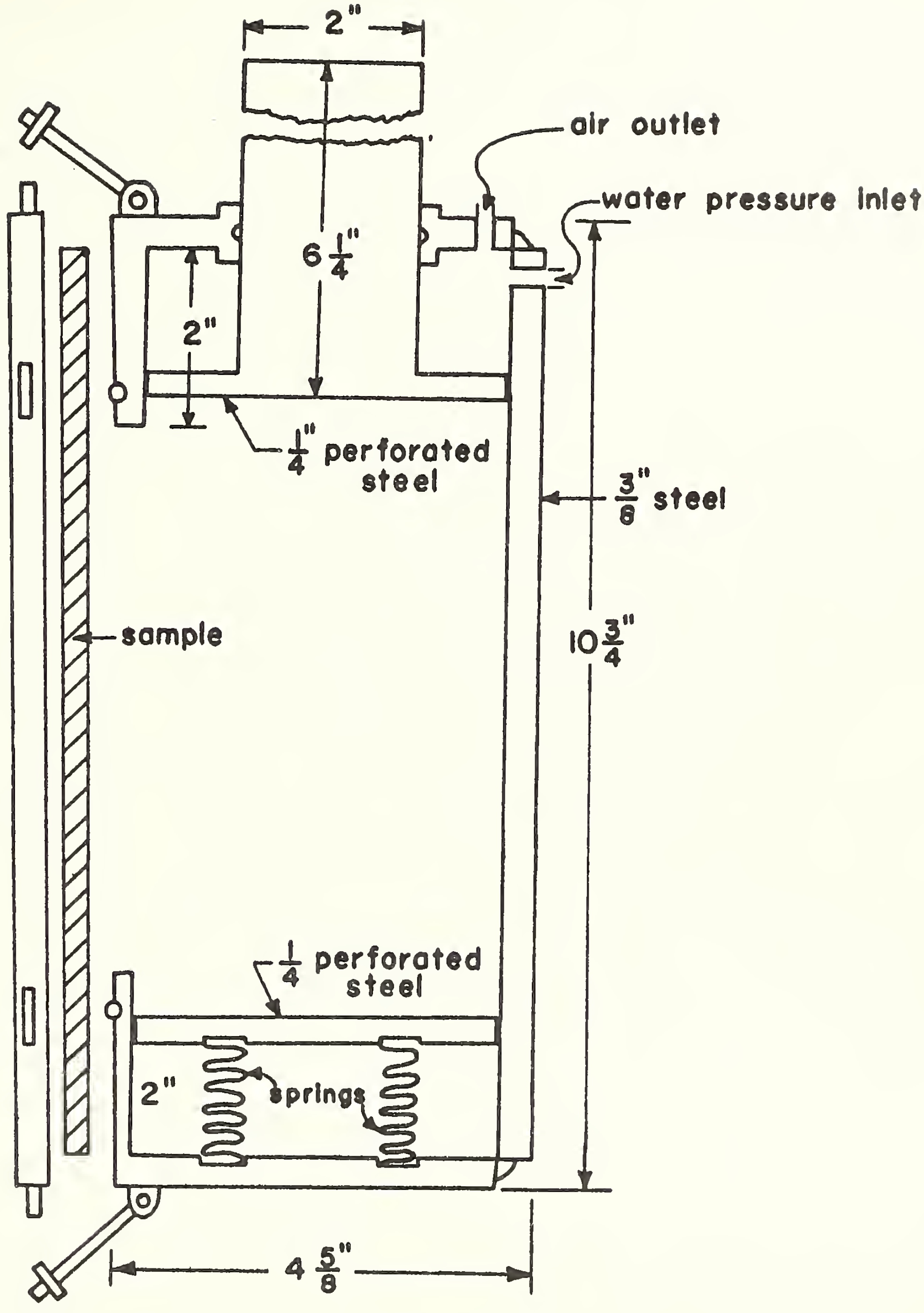

Figure 1. Simulated service test apparatus. The apparatus was designed to simulate conditions to which waterproofing systems are subjected.

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